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FACTORS CONTROLLING THE DISTRIBUTION OF DOUGLAS FIR IN SEMI-ARID REGIONS OF THE NORTHWEST

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The aim of the present investigation was to obtain quantitative data on the factors which control the distribution of Douglas fir (*Pseudotsuga taxifolia*) in semi-arid regions of northwestern United States. It has been pointed out, as the result of observations in different localities, that Douglas fir is confined largely to north facing slopes, while south slopes are practically without forest trees except where out-cropping rocks help to furnish sufficient shelter and moisture for the establishment of seedlings (2, 7, 10, 12). In that part of Idaho adjacent to the Spokane region in Washington, included in Merriam's Arid Transition Area (5), the Douglas fir grows chiefly on the north and northeast slopes. These are considerably steeper than the southwest slope. The prevailing winds are from the southwest.

Methods

Paradise Ridge and Tomer's Butte in Latah County, Idaho, four and five miles distant from Moscow, were selected as suitable stations for measuring the differences between the north-northeast and the south-southwest slopes. The forest condition on these two hills are fairly representative of the Spokane region in eastern Washington and adjacent Idaho.

The vegetation of the southwest slopes is sparse. An examination of the burned trunks of trees and of fallen logs reveals the fact that the previous forest was yellow pine (*Pinus ponderosa*). This is practically the only forest tree at the present time, and furnishes the small amount of reproduction that is taking place. A limited growth of Douglas fir may be found in ravines. These locations are protected to a certain extent from the prevailing winds, and receive considerable quantities of drifting snow. Thus the ravines present more favorable conditions for tree growth.

The vegetation on the northeast slope is often quite dense. An examination similar to that made on the south and southwest slopes reveals the fact that the previous forest was made up of a mixture of yellow pine and Douglas fir. The present forest is composed of a few trees of yellow pine in the less protected places. The greater part, however, is made up of dense stands of Douglas fir. Some larch (*Larix occidentalis*) may also be found in favorable locations.

The stations were visited once each week, and the following physical factors were measured: (1) the evaporating power of the air; (2) relative humidity; (3) water content of the soil; (4) temperature of the soil and air; (5) wind; (6) light. Transpiration from the branches of Douglas fir was also considered.

EVAPORATION

Evaporation was measured with Livingston porous cup atometers. Since the development of a forest depends upon the germination of its seeds and on the conditions to which the growth of the seedlings are subjected, it was considered desirable to measure the evaporation close to the surface of the soil. To accomplish this, holes were dug in which the bottle was inserted with only the neck protruding. This made the top of the porous cup evaporimeter about five inches above the ground. The usual precautions were taken to prevent the growth of algae in the water of the bottle. The water was completely changed in each bottle every week. Evaporation was measured for two consecutive years through the months of June, July, August, and September.

Graphs have been plotted only for the season of 1915 since the results of both years agree as to the general relationships in regard to evaporation. An examination of the graphs in figure 1 show that comparatively little evaporation takes place on either slope during June and September as compared with July and August. The greatest amount of evaporation on both slopes took place during the week ending August 10th. During that week 101 cubic centimeters more of water evaporated on the southwest slope than on the northeast slope. This great difference must have a direct bearing on the vegetation.

RELATIVE HUMIDITY

Humidity was measured by means of the sling psychrometer. This instrument is a modification of the pattern developed for the U. S. Weather Bureau. Table 1 shows the average relative humidity for the months of June, July, August, and September for the years 1915 and 1916; the difference between the two slopes is found in the fourth column. It will be seen that the highest humidity is always on the northeast slope at this season of the year.

TABLE 1. *Humidity*

	N. E. slope	S. W. slope	Difference
June	65	36	29
July	51	29	22
August	37	25	12
September	54	29	25

The higher humidity on the northeast slopes reduces the evaporation of water from the soil and also the amount of transpiration, thus making the conditions for plant life more favorable here than on the southwest slopes.

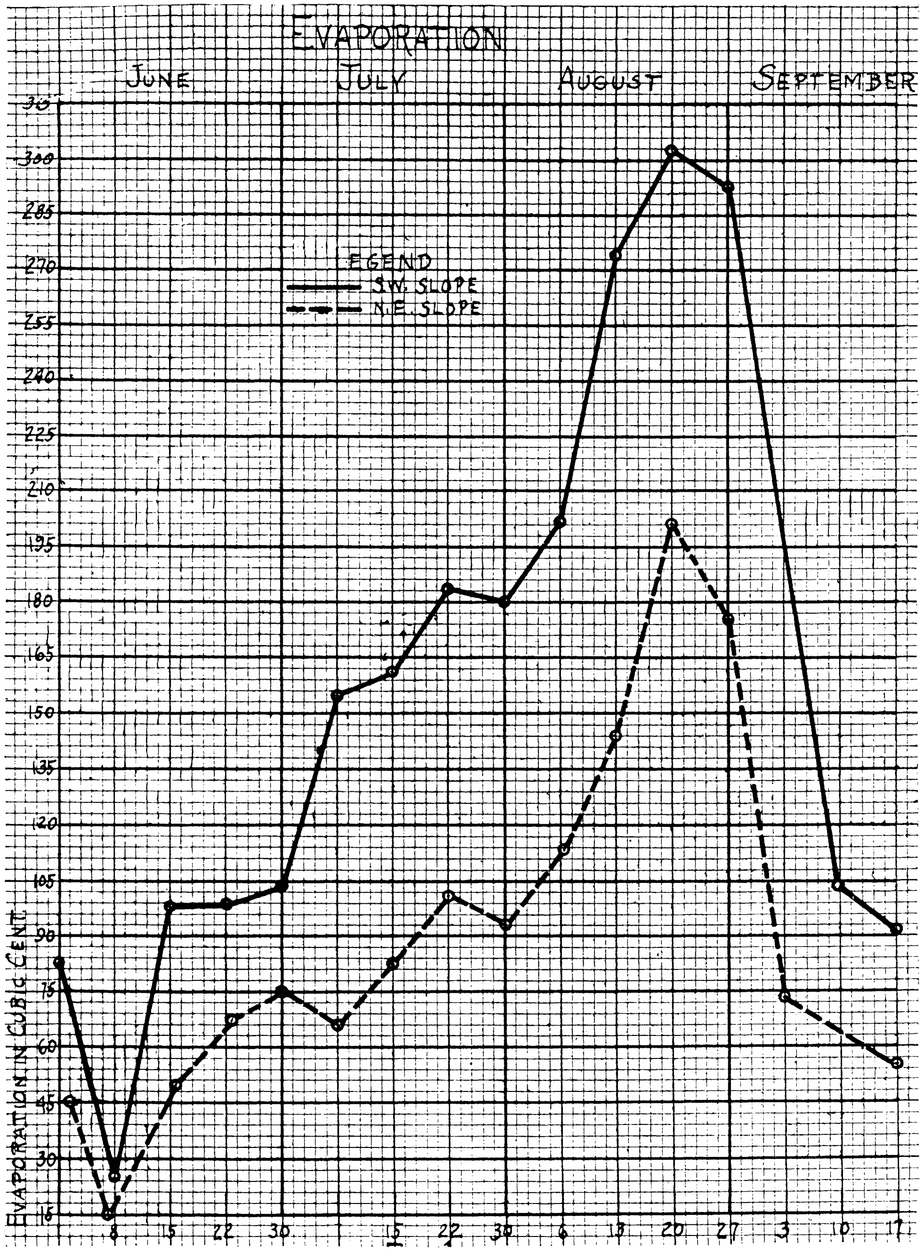

FIG. 1. Evaporation for 1915: on the southwest slope in the open (solid line), and on the northeast slope under yellow pine and Douglas fir forest (broken line). Weekly amounts in cubic centimeters.

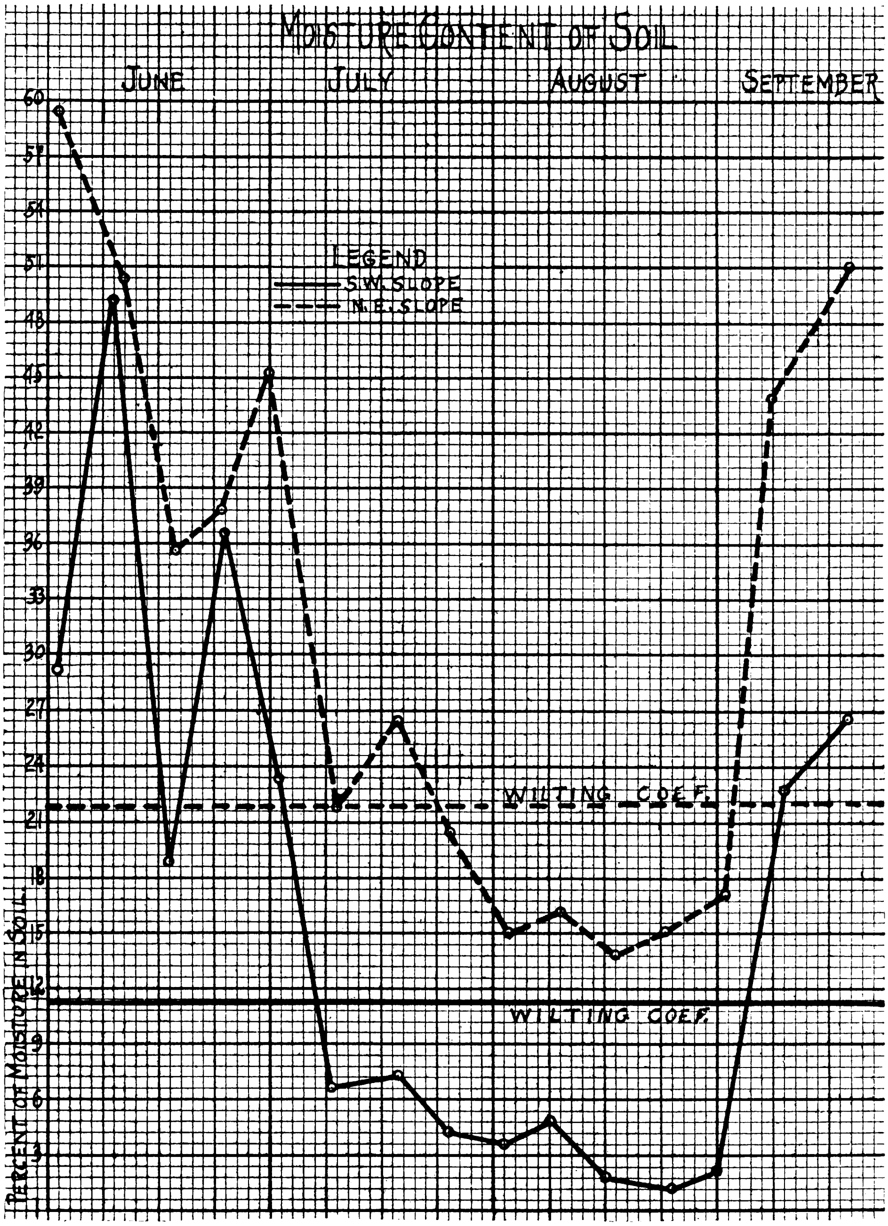

Fig. 2. Soil moisture for 1915 on the southwest slope (solid line) and northeast slope (broken line). The wilting coefficient for each slope is shown by the solid and broken horizontal lines.

WATER CONTENT OF THE SOIL

The soil at the two stations is residual, as is that of all the so-called mountains in this particular region. There is little doubt that the soil of the northeast and southwest slopes had much the same chemical composition before the coming in of the forest. At the present time the soil of the southwest slopes is about neutral (PH 6.8) while that of the northeast slopes is slightly more acid (PH 6.5). The soil on the north and northeast slopes contains more humus, and it is also finer in texture because the prevailing southwest winds have carried and deposited here considerable quantities of loessial material.

The southwest slope bears a prairie vegetation which the forest of yellow pine is slowly invading from ravines and protected places. The greater part of these slopes is without trees. The vegetation of the northeast slope may be a forest of yellow pine in the earlier stage of succession or in later stages a dense forest often largely or wholly made up of Douglas fir.

Soil samples for determining the water content were secured each week. A hole was dug about six inches in depth, with practically vertical sides. By use of a garden trowel, samples were obtained extending from the surface of the ground to the depth of the hole. Care was used to get a sufficient quantity of soil in each case to fill a standard soil can. The soil was placed in a Freas electric oven and dried at 105° F. to constant weight. The results, in percent, for the two slopes have been plotted in figure 2. It will be observed that on two occasions, during the first and last weeks of June, the moisture on the two slopes differed by less than 1 percent. This was due to rains occurring a short time previous to the taking of the soil samples. During June 1915 there was a rainfall of 2.20 inches, an unusually large amount for this month. In June 1916, there was only .40 of an inch.

A comparison of figures 1 and 2 shows that during the time when the evaporating power of the air was greatest, the percent of moisture in the soil was the least. By the end of the first week in August all of the annual herbaceous plants were dead. The leaves of *Balsamorrhiza sagittata* were curled up and many were dry and brittle. *Solidago missouriensis* and *Wyethia amplexicaulis* as yet showed little effect of the drouth except for some curling of the leaves. The roots of these plants penetrate deeply into the soil and were undoubtedly getting moisture from the deeper layers.

Soil for determining the wilting coefficient by the Briggs and Shantz method was secured from the two slopes after the manner previously described. Wheat seedlings were used, and six determinations were made on each slope. The average wilting coefficient on the southwest slope is 11.21, that on the northeast slope is 22.18.

An examination of figure 2 shows that the moisture in the first 6 inches of soil on the southwest slope was at or below the wilting ceofficient nearly 8 weeks during the growing season, while that on the northeast slope was at or below the wilting coefficient nearly five weeks. The soil moisture on northeast slopes under the Douglas fir forest was always above the wilting coefficient during the two seasons that this investigation was in progress.

TEMPERATURE

The temperature of both the air and the soil from June 1 to September 11 was recorded by means of two Richard thermographs. One was installed on the southwest and the other on the northeast slope of Tomer's Butte, each being about 100 feet vertically distant from the crest. The thermographs were checked each week with standard thermometers. The highest air temperature reached on either slope was during the week ending August 28. On the southwest slope this was 125° F. At this time the temperature varied from 34° to 125° between 6:00 A.M. and 2:00 P.M., or a range of 81° in eight hours. The maximum on the northeast slope did not exceed 80° at 2:00 P.M. and the minimum was 43° at about 6:00 A.M., or a range of 37°.

The temperature of the soil was recorded at a depth of about four inches. The greatest range in soil temperature from about 10:00 A.M. to 5:00 P.M. on the southwest slope was nearly 10°, while that on the northeast slope was 3½°.

The graphs in figure 3 illustrate the characteristic difference between the air and soil temperatures on the two slopes. The fluctuations on the southwest slope are seen to be not only greater in amplitude but more abrupt than those on the northeast slope.

WIND

Readings were made on the velocity of the wind during the months of June, July, August, and September, 1916. The Standard anemometers obtained from the C. H. Stoelting Company, Chicago, were used for this purpose. One anemometer was located on the southwest slope and another on the northeast slope, each about 100 feet vertically distant from the crest of the Butte, and each elevated about five feet above the surface of the ground. Since the Standard anomometer must be read each day, its use for a continuous record is difficult except when the stations are near by. The readings were, therefore, made for two-hour periods only. The greatest velocity of wind recorded on the southwest slope was 50 miles per hour, and on the northeast slope 4½ miles per hour. This great difference is due to the fact that the southwest slope is exposed to the prevailing winds, while the northeast slope is protected. The forest cover as well as the topography has much to do with the fact that wind is often scarcely discernible on

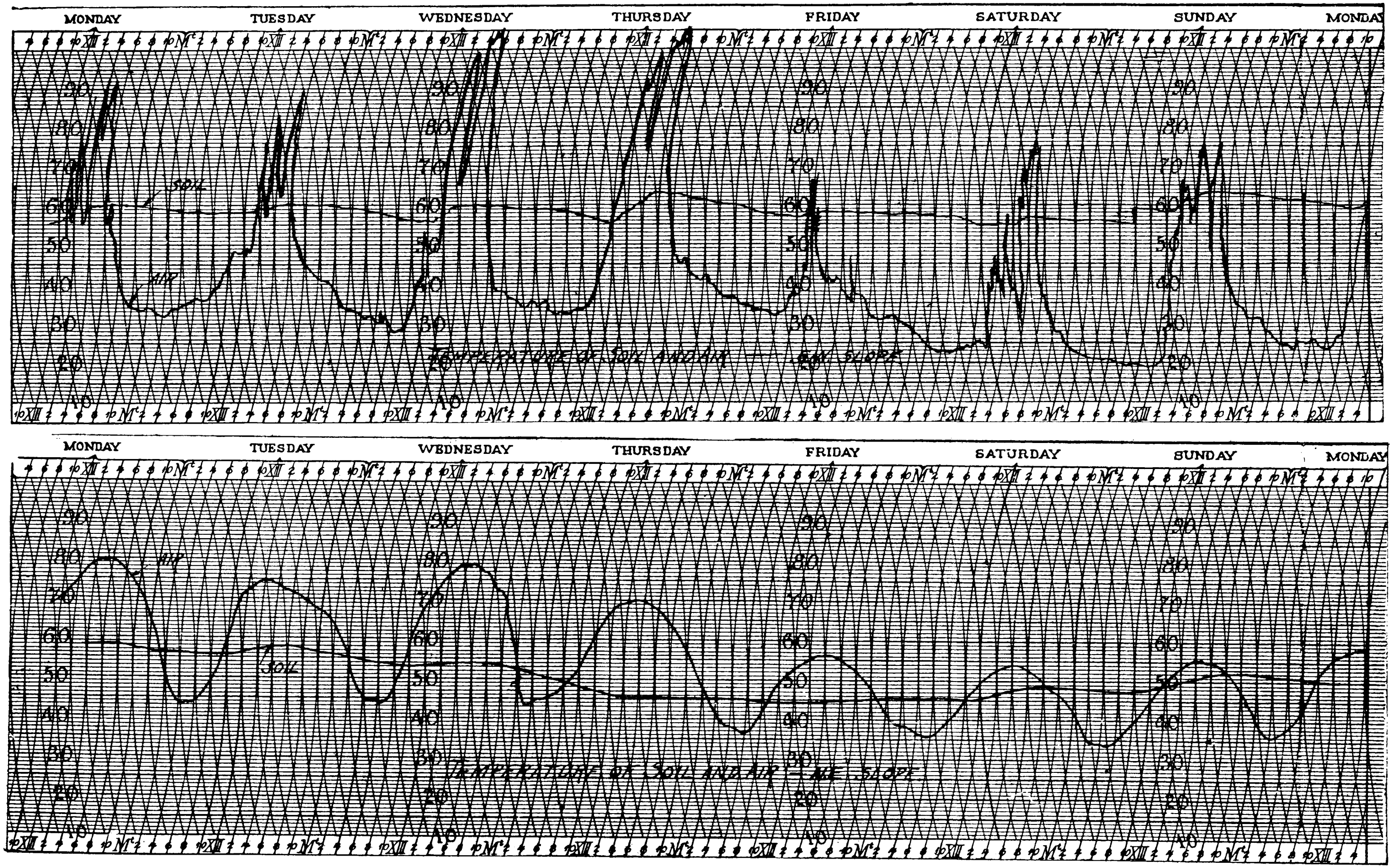

FIG. 3. Typical records of soil and of air temperature; above for the southwest slope, below for the northeast slope.

northeast slopes. The average velocity of the wind from June to September of 1916 will be found in table 2. The wind movement, based on one reading each week, is more than 19 times greater on the southwest than on the northeast slope.

TABLE 2. *Average wind velocity in miles per hour*

	S. W. Slope	N. E. Slope	Difference
June	42 miles	2½ miles	39½ miles
July	14 miles	1⅓ miles	12⅔ miles
August	27 miles	1 mile	26 miles
September	30 miles	1 mile	29 miles

LIGHT

Light was measured by the Clements photometer. If the amount of light received on the unforested part of the slope is considered as unity, the amount received under the cover of the yellow pine on the southwest slope is found to be .45, while that received under the cover of Douglas fir on the northeast slope is only .05. It is well known that the yellow pine was the first invader of the forest trees on the northeast as well as on the southwest slopes. Although light, of itself, is not a factor in causing Douglas fir to be confined to the north and northeast slopes, the reduced amount of light under the cover of the yellow pine and Douglas fir is of importance in causing the decrease of the former on these sites. Its decrease is not due to the higher water content of the soil or to the greater relative humidity since it is found flourishing in localities where both of these factors are in excess of those on north and northeast slopes. It is not temperature that eliminates it; the extremes of the temperature of both the air and the soil on the north and northeast slopes have been shown to be well within the limits of those on the southwest slopes. The indications point to light as a very important limiting factor in the disappearance of yellow pine from northeast slopes which have been invaded by Douglas fir.

TRANSPIRATION

The conditions affecting transpiration are temperature, humidity of the air, velocity of the wind, and light. Since all these factors are different on the two slopes under consideration, it was deemed advisable to make a study of transpiration. Branches of similar size, shape and age, and apparently of equal vigor, each bearing 400 needles were cut under water. The base of the branch was inserted accurately into one end of rubber tubing of a suitable size. The other end of the rubber tubing had been fastened to the base of the burette graduated to .01 cc. and filled with water. The burettes with their branches were suspended in an upright position on each slope about five feet above the surface of the ground in representative habitats. The experiments were never begun earlier than 11:00 A.M. or continued later than 3:00 P.M., and were run in duplicate on each slope to serve as a check on each other. Readings were taken simultaneously on both slopes at the close of the two-hour periods. The average of the transpiration of the two potometers on each slope is given in table 3. The transpiration is in terms of cubic centimeters of water lost from the burettes. There was, at the time the experiment was conducted, always more transpiration on the southwest than on the northeast slope, the former showing an average of 2.89 times as much water loss as the latter.

TABLE 3. *Transpiration July 25 to August 11, 1916*

Species	Time	S. W. slope	N. E. slope
Douglas fir	11:45–1:45	1.21	0.20
	11:15–1:15	3.20	1.00
	12:30–2:30	1.80	0.70
	12:45–2:45	3.10	1.30
	11:00–1:00	2.60	1.40
	11:20–1:20	3.50	1.10
	12:25–2:25	3.40	0.80
Total		18.81	6.50

DISCUSSION

The high evaporating power of the air, caused largely by the prevailing southwest winds, is very detrimental to plant life on the southwest slope in this region. The low water content of the soil, the low relative humidity and the high temperatures, accompanied by the high rate of transpiration, make the conditions too rigorous for the more mesophytic types of forest trees, such as the Douglas fir, on the south and southwest slopes.

Germination of the seeds of Douglas fir and of yellow pine takes place about the middle of April. Very little germination of forest tree seed occurs on the south or southwest slopes, and less than one percent of the seed that does germinate ever endures the drouth of the first growing season. By the middle of June when the roots are beginning to penetrate the soil, the dry season begins, the transpiration increases and soon more water is lost than can be taken up by the roots. The seedlings soon wilt and by the middle of July or earlier they are brown in color and all signs of life extinct. Rarely, even where the seed has germinated under the protection of a protruding rock, are yellow pine seedlings living at the end of the growing season. The writer has never found a Douglas fir seedling alive on the southwest slope after the beginning of August. This must be attributed to lack of soil moisture and to the high transpiration which takes place at this season, as shown in figure 2 and table 3.

The destructive effects of low temperature, wind and loss of water during the winter season were well shown in the spring of 1917. The yellow pine saplings and trees on the southwest slopes had practically all of their needles killed on the half of the tree facing the southwest winds; the soil on these slopes was frozen to a considerable depth for a period of nearly four months. Pearson (6) states that when the tempearture of the soil falls to 32° F., or even a few degrees above 32°, the moisture of the soil is no longer available to the roots of the plants. The killing of these leaves can hardly be explained on any other basis than that the winds dried out the tissues of the needles on the exposed side of the tree during this long period when the temperature of the soil was so low that moisture was not available to the roots of the plants. The few Douglas firs growing on the southwest slope, though in sheltered localities, had a much larger percent of their needles killed. The forest trees on the northeast slope were uninjured.

Conclusions

1. The velocity of the wind is usually much greater on the southwest slopes than on the northeast slopes in this region. Readings taken during the time this work was being conducted showed the average wind velocity to be 19 times greater on the former than on the latter sites.

2. The relative humidity during the summer is much lower on the southwest than on the northeast slopes in this region.

3. The high velocity of the wind causes a much higher rate of evaporation and transpiration on the southwest than on the northeast slopes. This high evaporation from the soil during the season when the average rainfall is often less than .40 of an inch per month, reduces the amount of water in the upper layers of the soil to a point where the amount lost by transpiration exceeds the amount available for the use of the plant.

4. The high temperatures and wide fluctuations of temperature on the southwest slopes seem to prevent the growth of the Douglas fir on these slopes only in as much as they promote evaporation and transpiration.

5. The want of sufficient moisture in the surface soil on southwest slopes and the low humidity often prevent the germination of seeds and also proves fatal to young seedlings especially of the mesophytic type such as the Douglas fir. Low moisture content of the soil is considered the greatest factor in preventing the growth of Douglas fir on southwest slopes.

6. Low soil temperatures, 32° F., persisting over long periods of time, accompanied by high winds, prove fatal to seedlings by rendering the soil moisture unavailable for the plants on the southwest slopes.

7. Reduced light under the cover of Douglas fir is the chief factor in causing the disappearance of yellow pine on the north and northeast slopes.

Acknowledgment is due to Mr. Frank H. Thomas for his able assistance in helping to carry out this investigation.

It is planned to continue these investigations by studying the effect of soil texture and its relation to moisture conditions as well as the effect of the different types of forest trees on soil moisture.

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